The AI of the Beholder in Medical Imaging

Jeff Fessler

DUP Talk

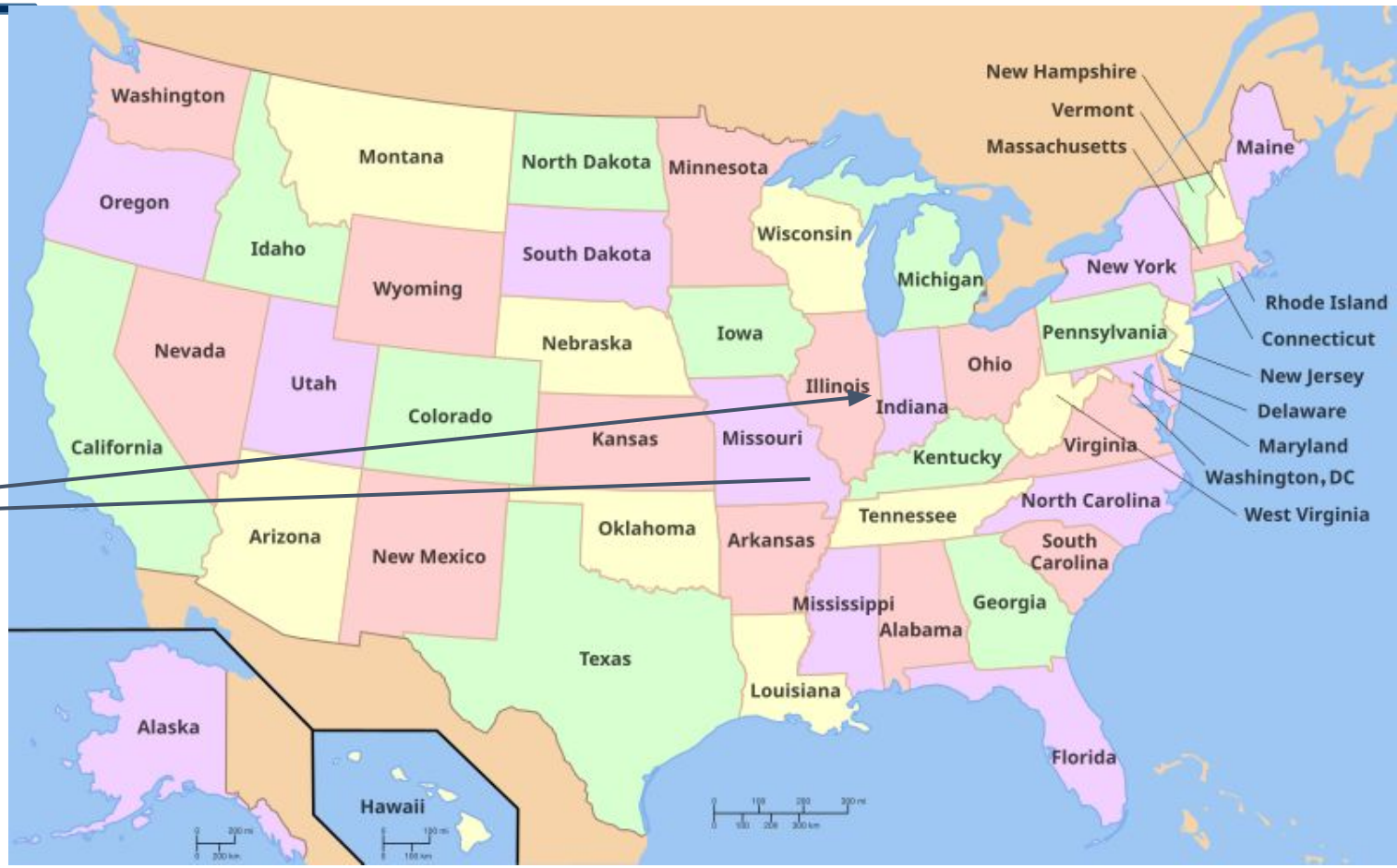
2025-09-25

University Hall – Ruthven Administration Bldg

youtube: https://www.youtube.com/watch?v=JRuxdgmkqmI

My career journey

- Indiana/Purdue
  1964-1985
- Stanford
  1985-1990
- Michigan
  1990 - now
  (Go Blue!)

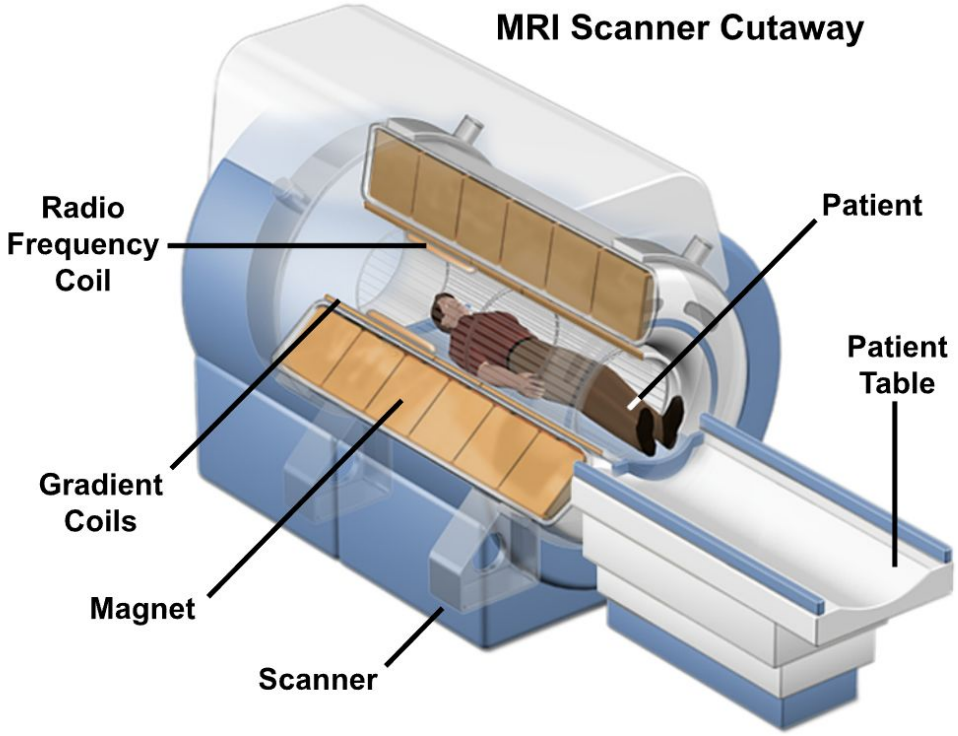


https://upload.wikimedia.org/wikipedia/commons/a/a5/Map_of_USA_with_state_names.svg

Ubuntu

I am, because we are

AI/ML in Medical Imaging - Under the hood



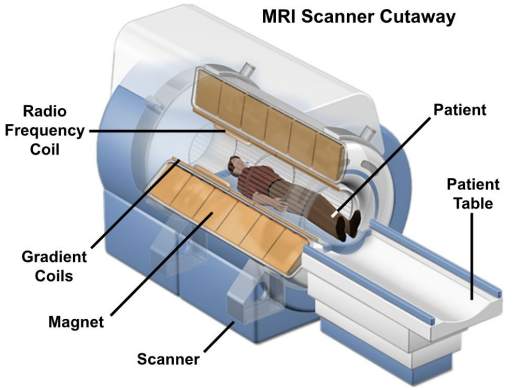
Ailment

X-ray Imaging

X-ray Images

Orthopedist

MR Imaging



MR Images

Radiologist Read

Diagnosis

FINDINGS:

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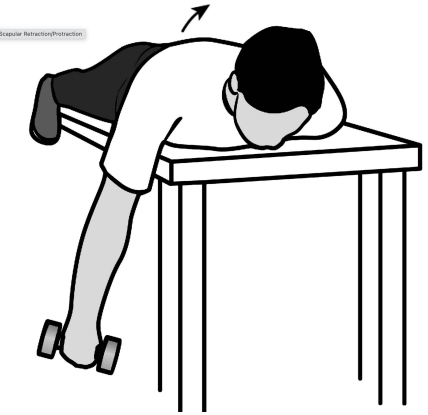
Treatment Plan

Treatment



What diagnostic tests?

Ailment → ??? → X-ray Imaging → X-ray Images

- To image or not to image…
- X-ray? CT? MRI? Ultrasound? SPECT? PET?
- X-ray contrast (dye) or non-contrast?
- …

What diagnostic tests?

Ailment → ??? → X-ray Imaging → X-ray Images

Research: AI-Driven Clinical Decision Support Systems

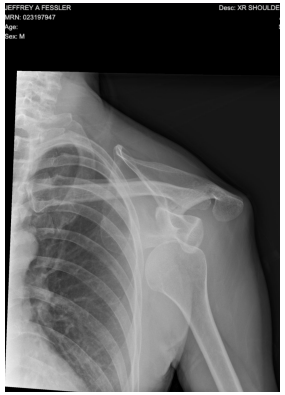
https://doi.org/10.7759/cureus.57728

MRI is very versatile

Ailment

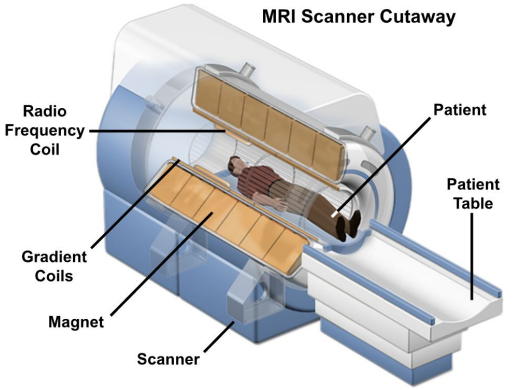
X-ray Imaging

X-ray Images



Orthopedist

MR Imaging



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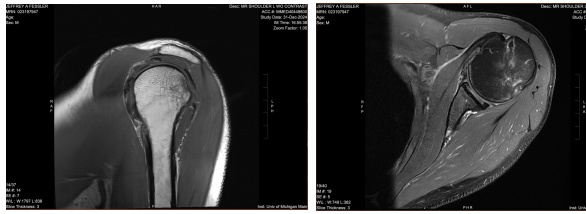
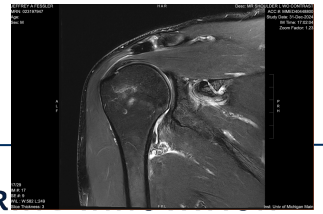




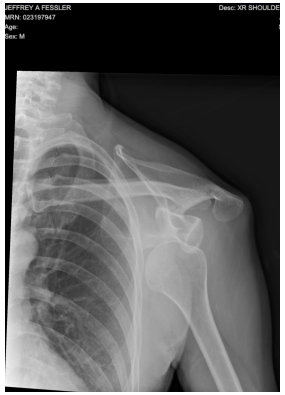
- MRI scanners have 100s of protocols
- Each protocol has dozens of selectable parameters (perspective, # slices & pixels, contrast, …)
- …

MRI is very versatile

Ailment

X-ray Imaging

X-ray Images



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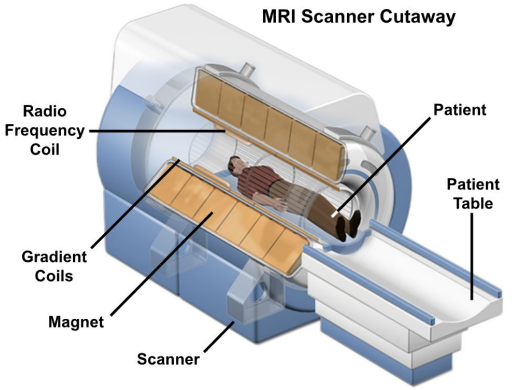

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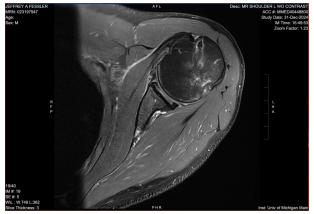

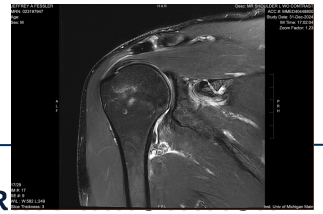

Research: AI-based protocoling

https://doi.org/10.1007/s10278-022-00610-1

Radiologist interpretation

- Stacks and stacks of 2D images of 3D anatomy

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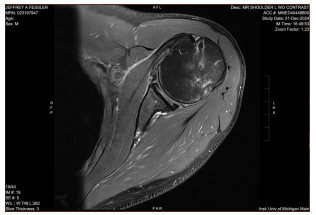
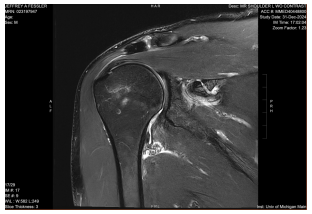
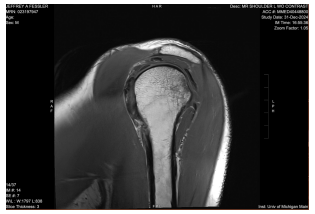
Radiologist Read

MR Images







AI-assisted diagnosis

- Computer vision? 2D vs 3D?
- Research: AI-based image classification / image analysis

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Radiologist Read

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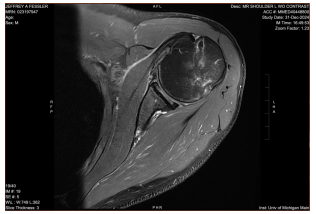
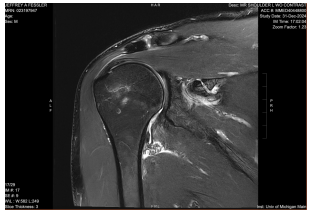
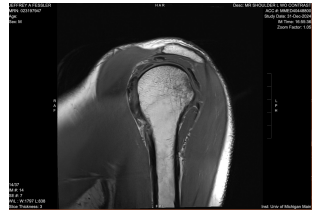
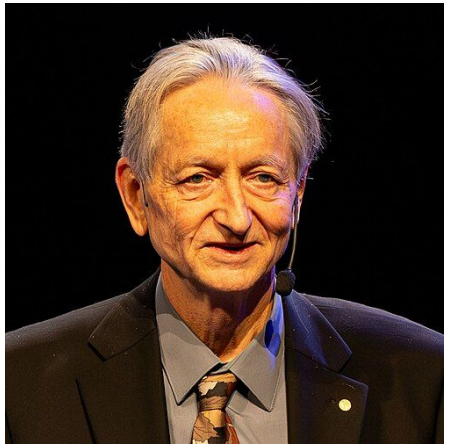






AI-assisted diagnosis

- Geoffrey Hinton 2016: "People should stop training radiologists now... it's just completely obvious that within five years deep learning is going to do better than radiologists"
- 2024 Nobel Prize in Physics



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AI/ML devices

Singh et al, npj Digital Medine

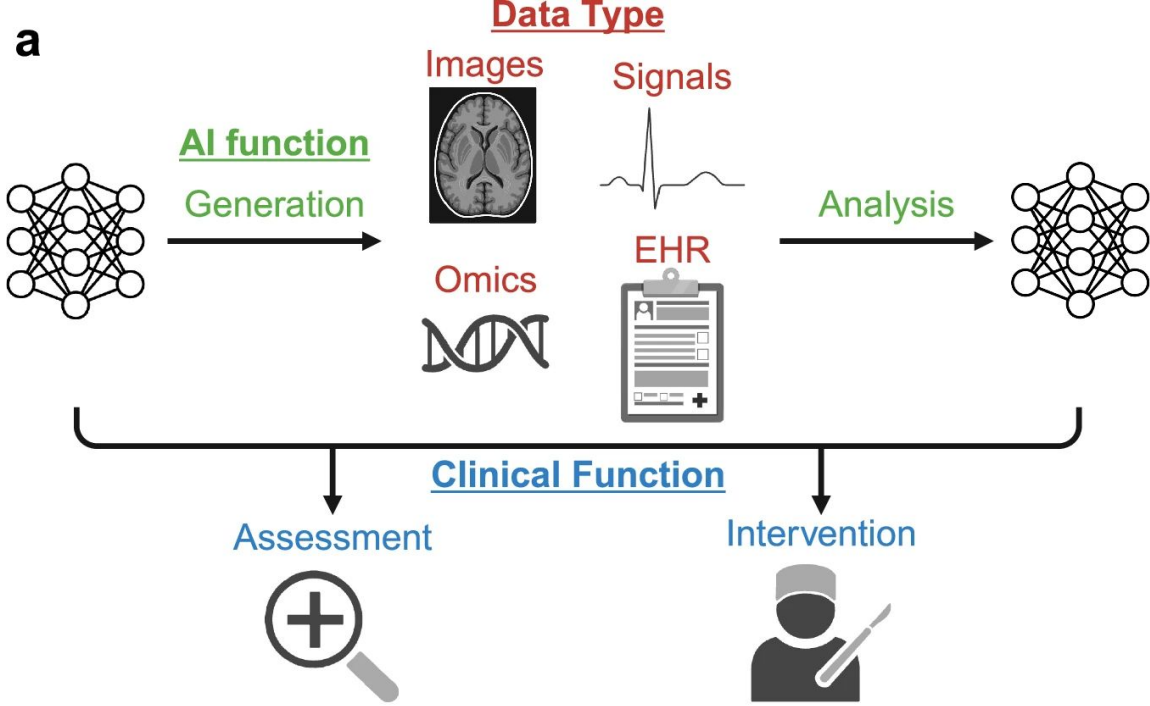
July 2025

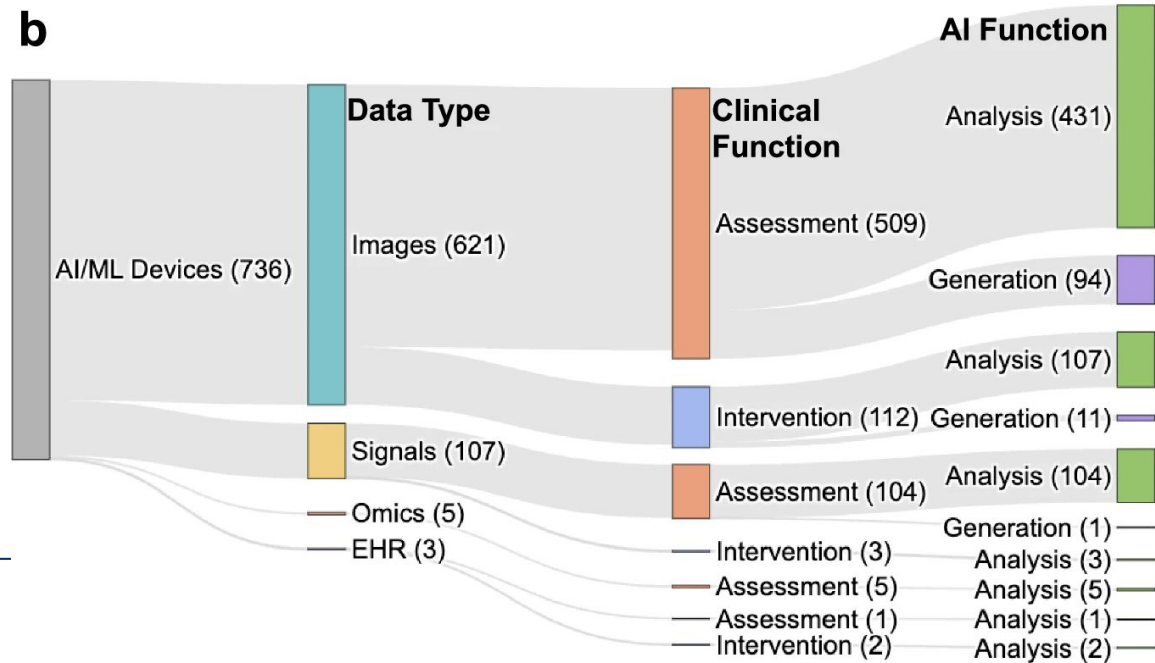
> 1000 FDA-authorizations

of 736 unique “devices”

Beyond R&D

https://doi.org/10.1038/s41746-025-01800-1



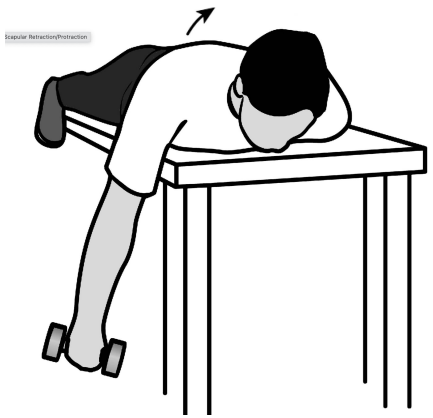


Treatment planning

- Research: AI-assisted treatment planning and monitoring (pharmaceuticals, radiation delivery…)

https://doi.org/10.1200/JCO.2024.42.16_suppl.1523

Treatment



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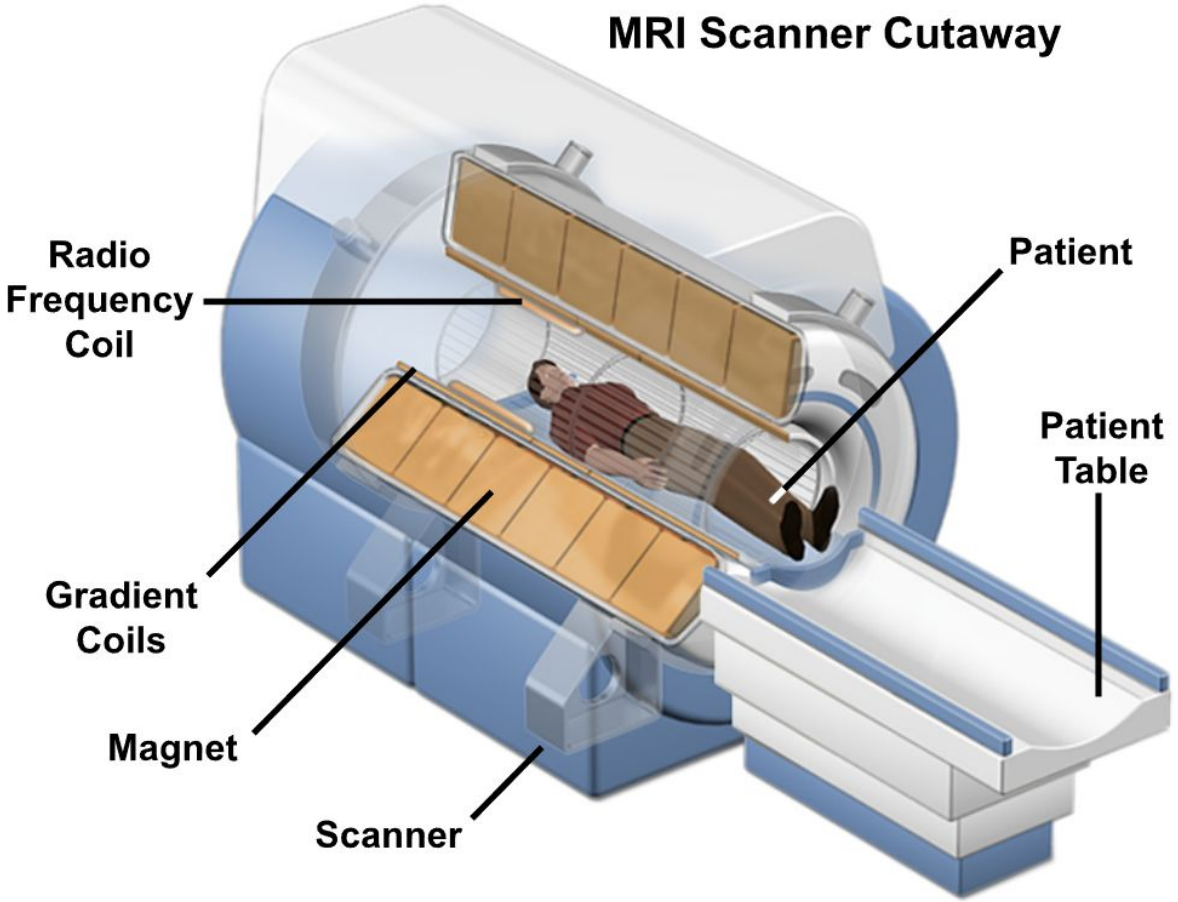
AI/ML in Medical Imaging - Under the hood

- RF coil(s)
  (transmit and sense)
- gradient coils



Why?

- Reduce scan time (cost, comfort, motion)
- Make scans quieter
- Improve image quality (resolution, noise)
- Make images more quantitative
- Make scans more reproducible (between and within vendors/sites)
- Make images that better relate to tissue pathology (e.g., in white matter)

MRI sampling and reconstruction

Raw k-space data

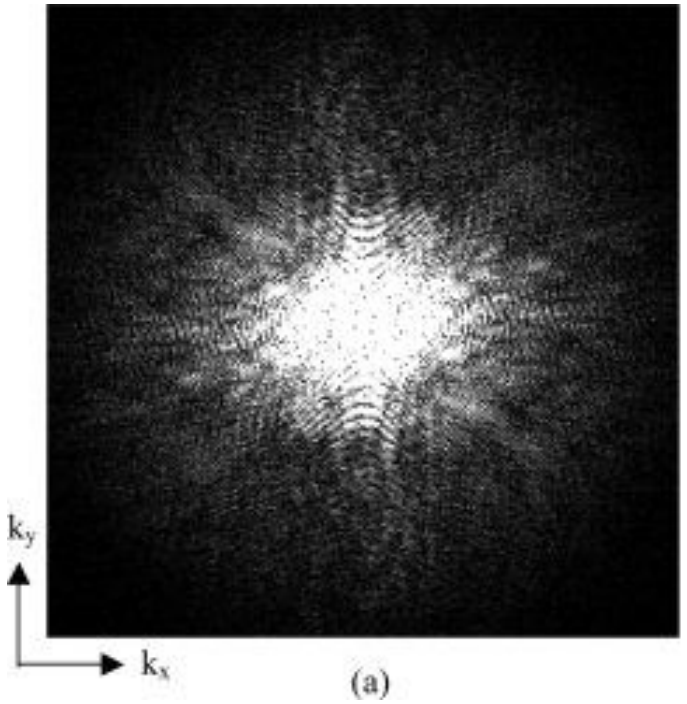


Image Reconstruction Magic

$$\hat{\boldsymbol{x}} = \arg\min_{\boldsymbol{x}} \frac{1}{2} \|\boldsymbol{A}\boldsymbol{x} - \boldsymbol{y}\|_2^2 + \beta \|\boldsymbol{T}\boldsymbol{x}\|_1 .$$

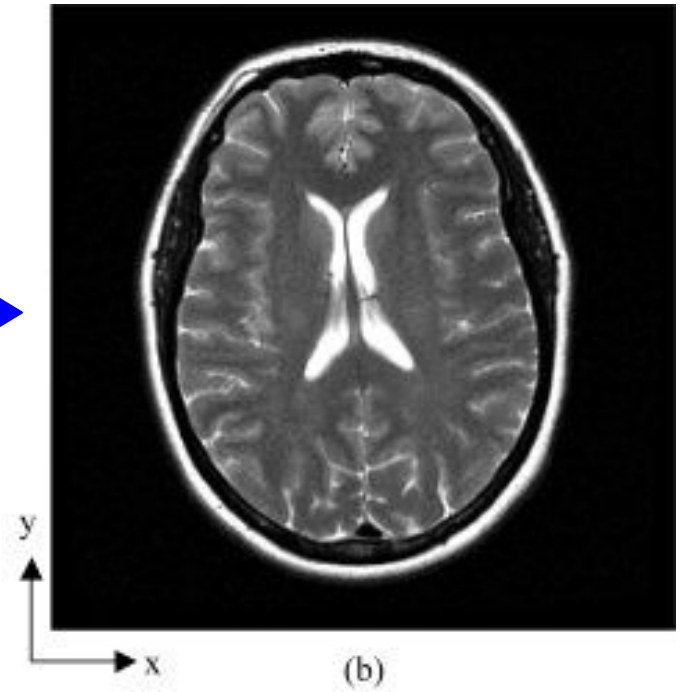
$$\hat{\boldsymbol{x}} = \arg\min_{\boldsymbol{x}} \frac{1}{2} \|\boldsymbol{A}\boldsymbol{x} - \boldsymbol{y}\|_2^2 + \beta R(\boldsymbol{x})$$
$$R(\boldsymbol{x}) = \min_{\boldsymbol{z}} \frac{1}{2} \|\boldsymbol{x} - \boldsymbol{D}\boldsymbol{z}\|_2^2 + \alpha \|\boldsymbol{z}\|_1 .$$

$$\hat{\boldsymbol{x}} = \boldsymbol{D}\hat{\boldsymbol{z}}, \quad \hat{\boldsymbol{z}} = \arg\min_{\boldsymbol{z}} \frac{1}{2} \|\boldsymbol{A}\boldsymbol{D}\boldsymbol{z} - \boldsymbol{y}\|_2^2 + \beta \|\boldsymbol{z}\|_1$$

$$\min_{\boldsymbol{x}_L, \boldsymbol{x}_S} \frac{1}{2} \|\boldsymbol{A}(\boldsymbol{x}_L + \boldsymbol{x}_S) - \boldsymbol{y}\|_2^2 + \lambda_L \|\boldsymbol{R}_1(\boldsymbol{x}_L)\|_* + \lambda_S \|\boldsymbol{T}\boldsymbol{x}_S\|_1 .$$

$$\hat{\boldsymbol{X}} = \arg\min_{\boldsymbol{X} \in \mathbb{C}^{M \times N}} f(\boldsymbol{X}) + \beta \sum_{s \in \Lambda} \sum_{p \in \Gamma} \|\mathcal{P}_p(\mathcal{S}_s(\boldsymbol{X}))\|_*$$

Reconstructed Image



http://dx.doi.org/10.1002/jmri.10451

MRI sampling and reconstruction

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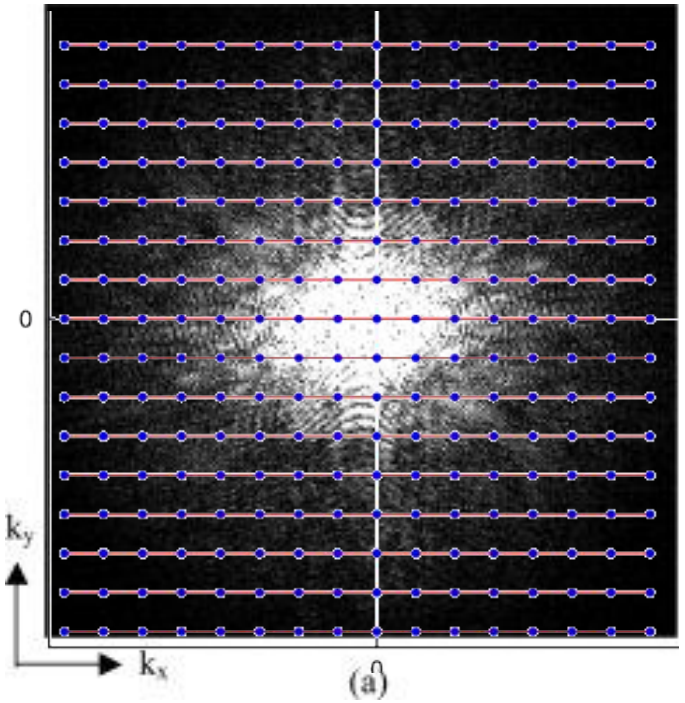

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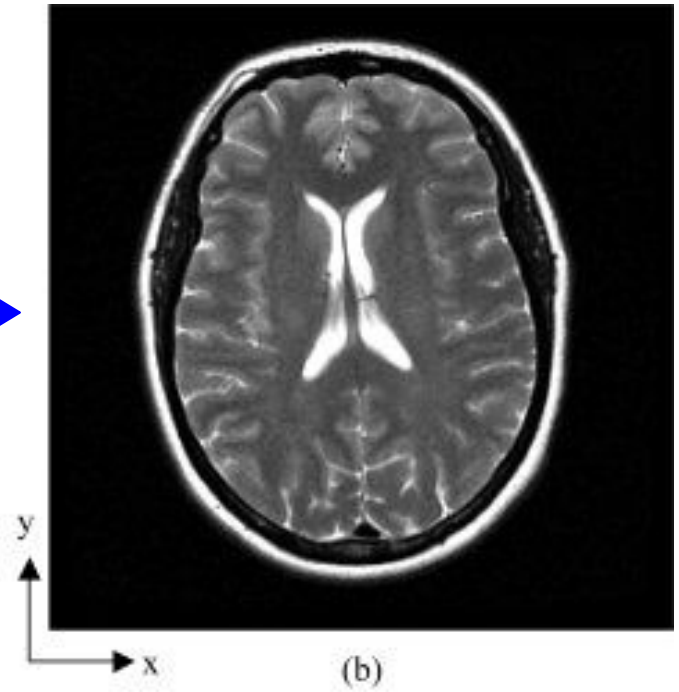

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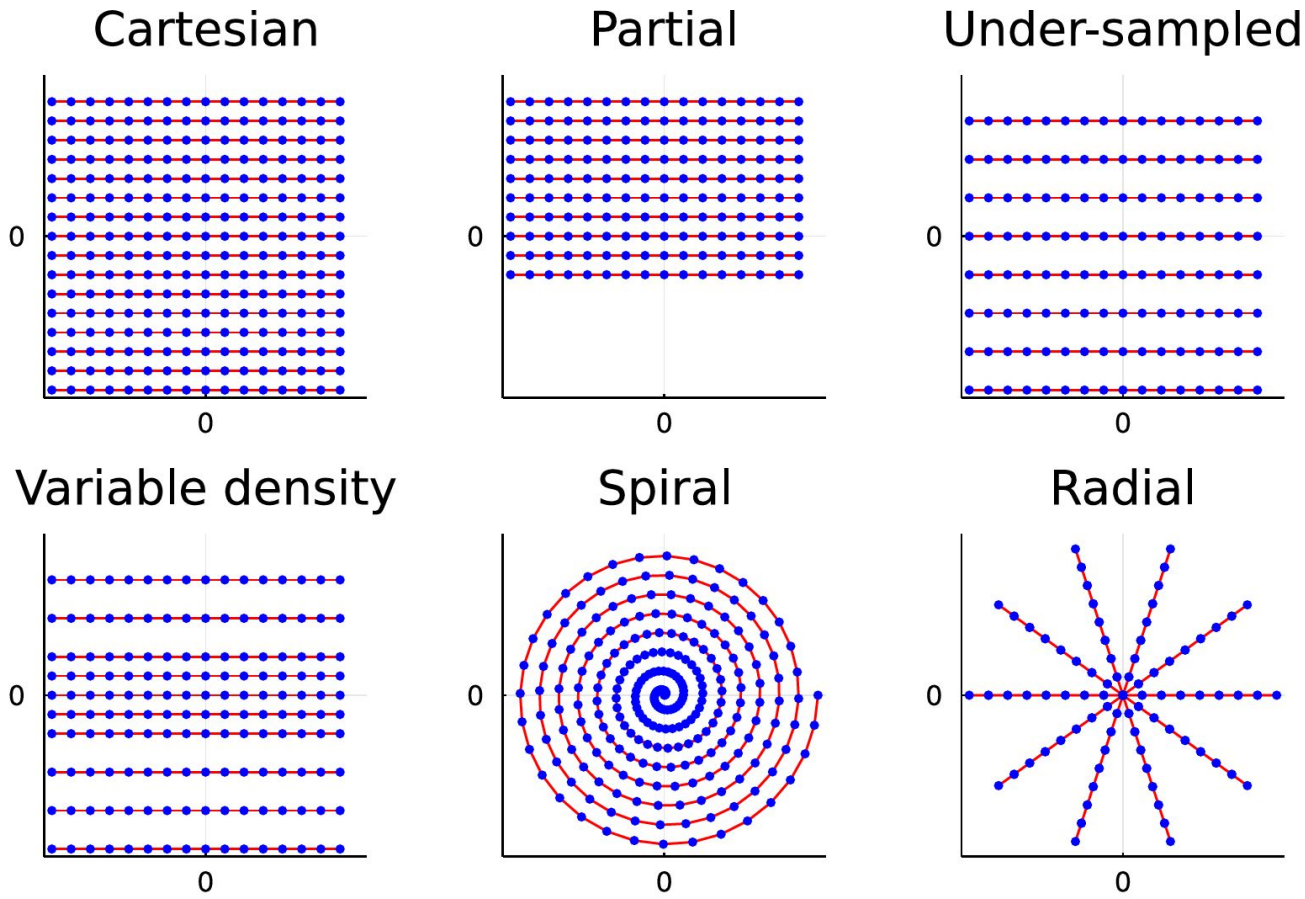
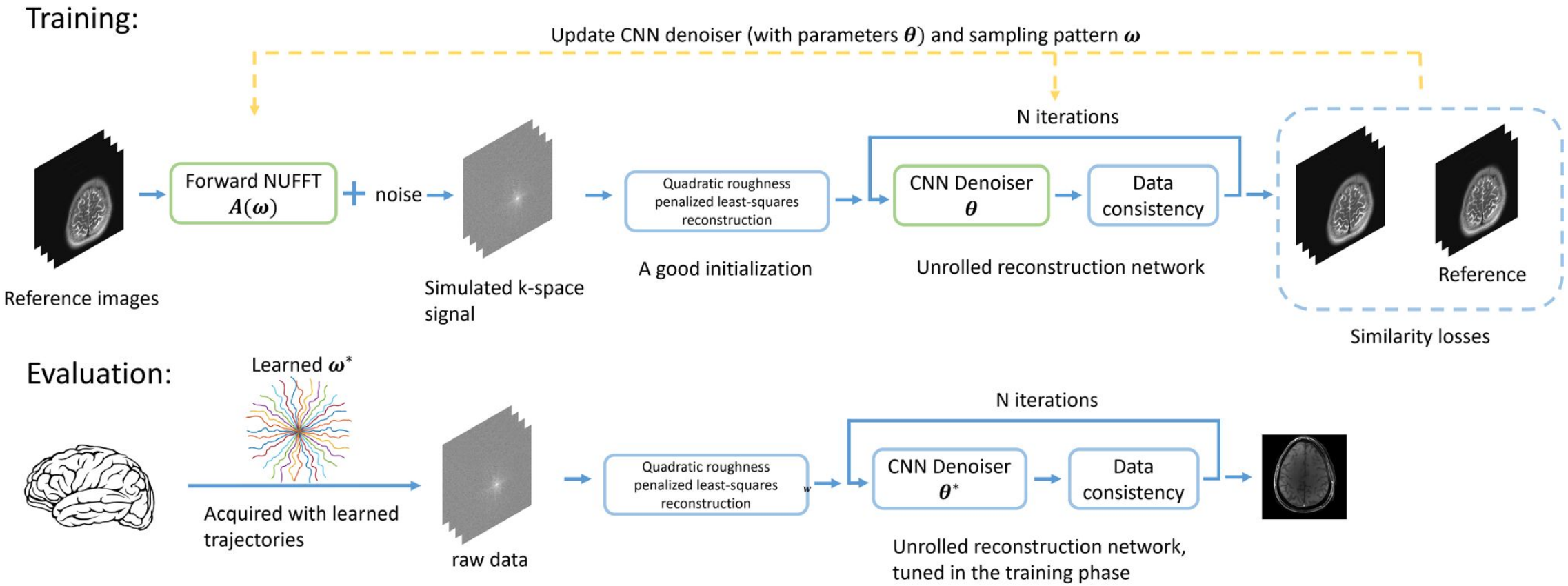
Hand-crafted k-space sampling in MRI

- All are used
- Any best?



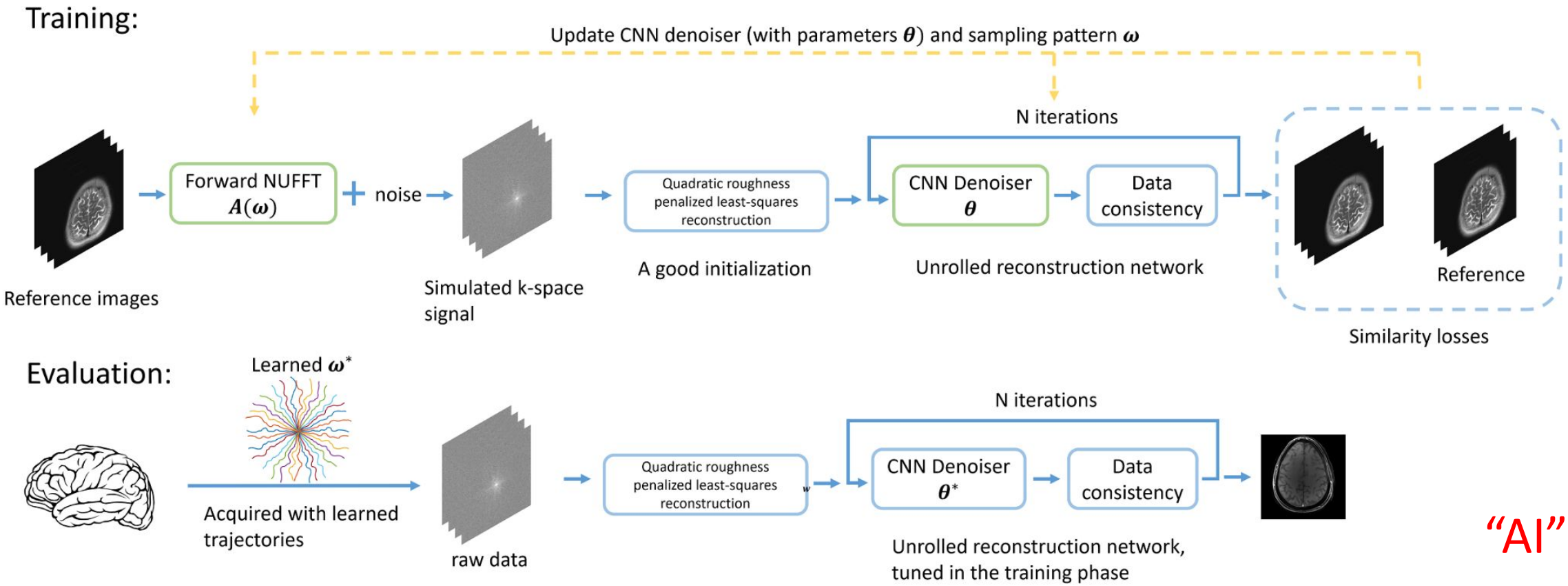
ML-based design of k-space sampling in MRI



B-spline parameterized joint optimization of reconstruction and k-space trajectories (BJORK)

Wang, Luo, Nielsen, Noll, JF: IEEE T-MI, 2022

ML-based design of k-space sampling in MRI



"AI" ?

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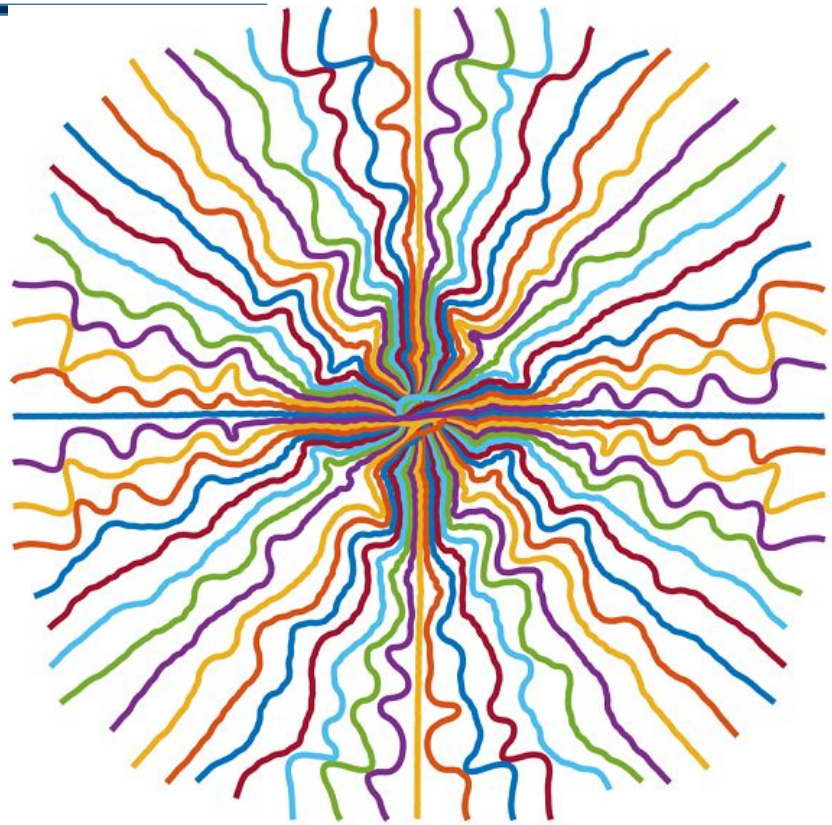
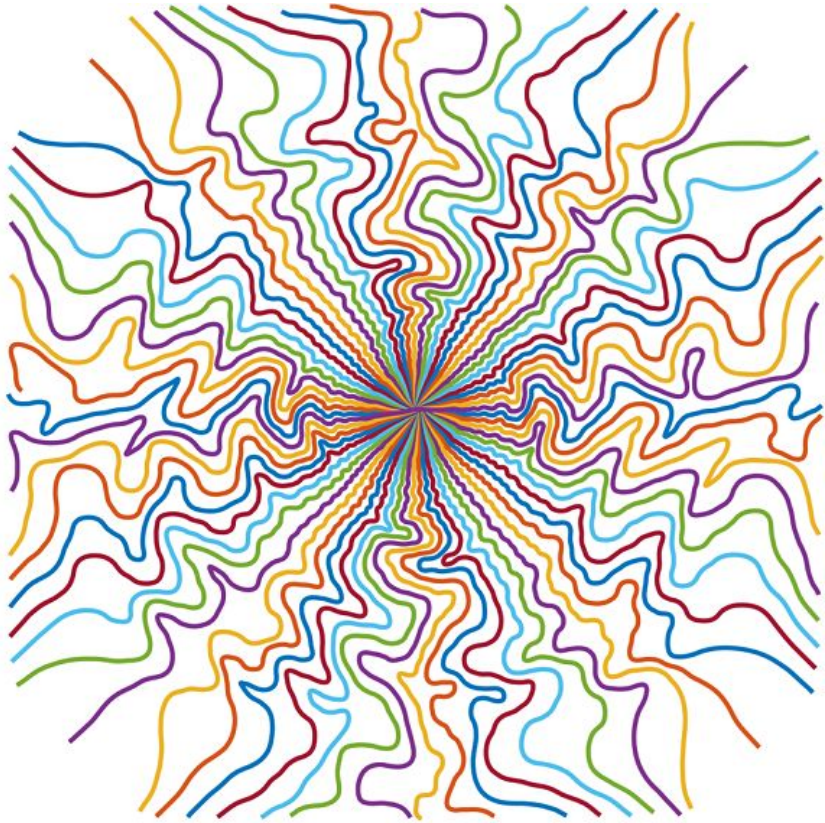
Anatomy specific sampling

- BJORK
- Wang et al. IEEE T-MI 2022

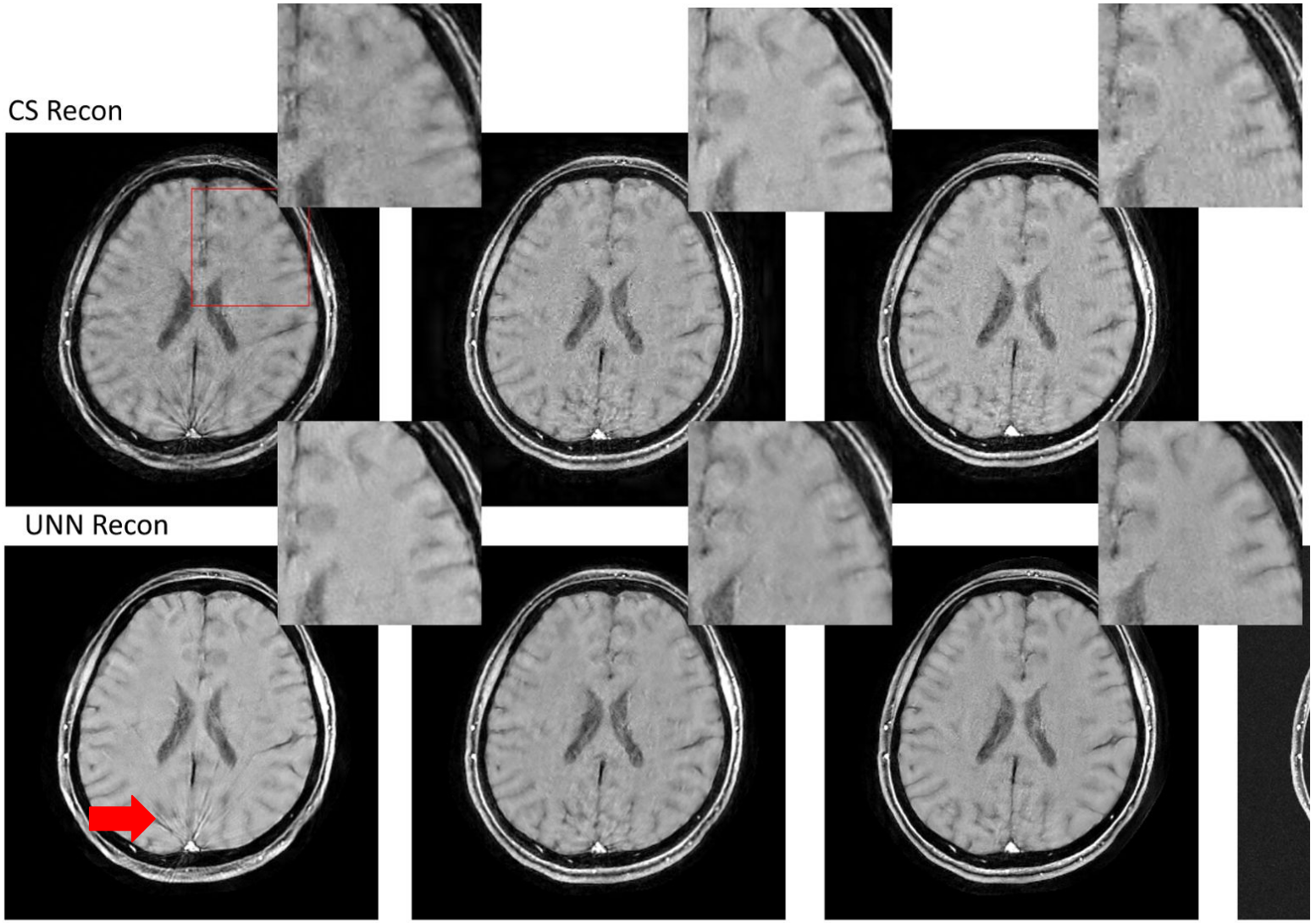


Knee



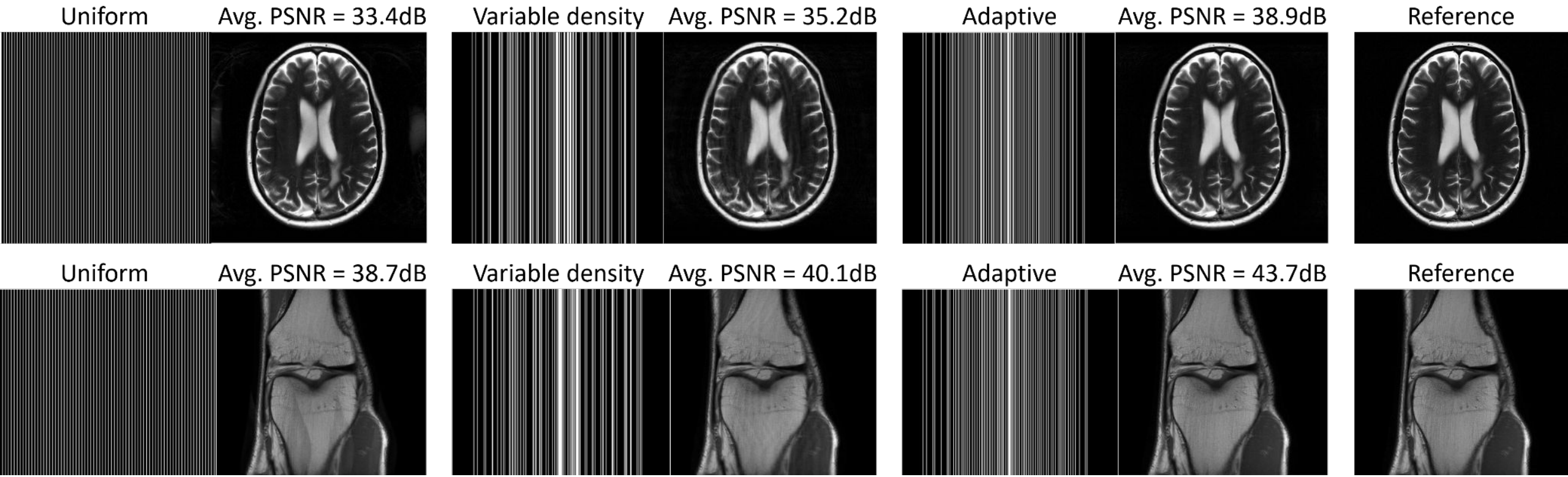
Brain

Prospective in-vivo MRI results

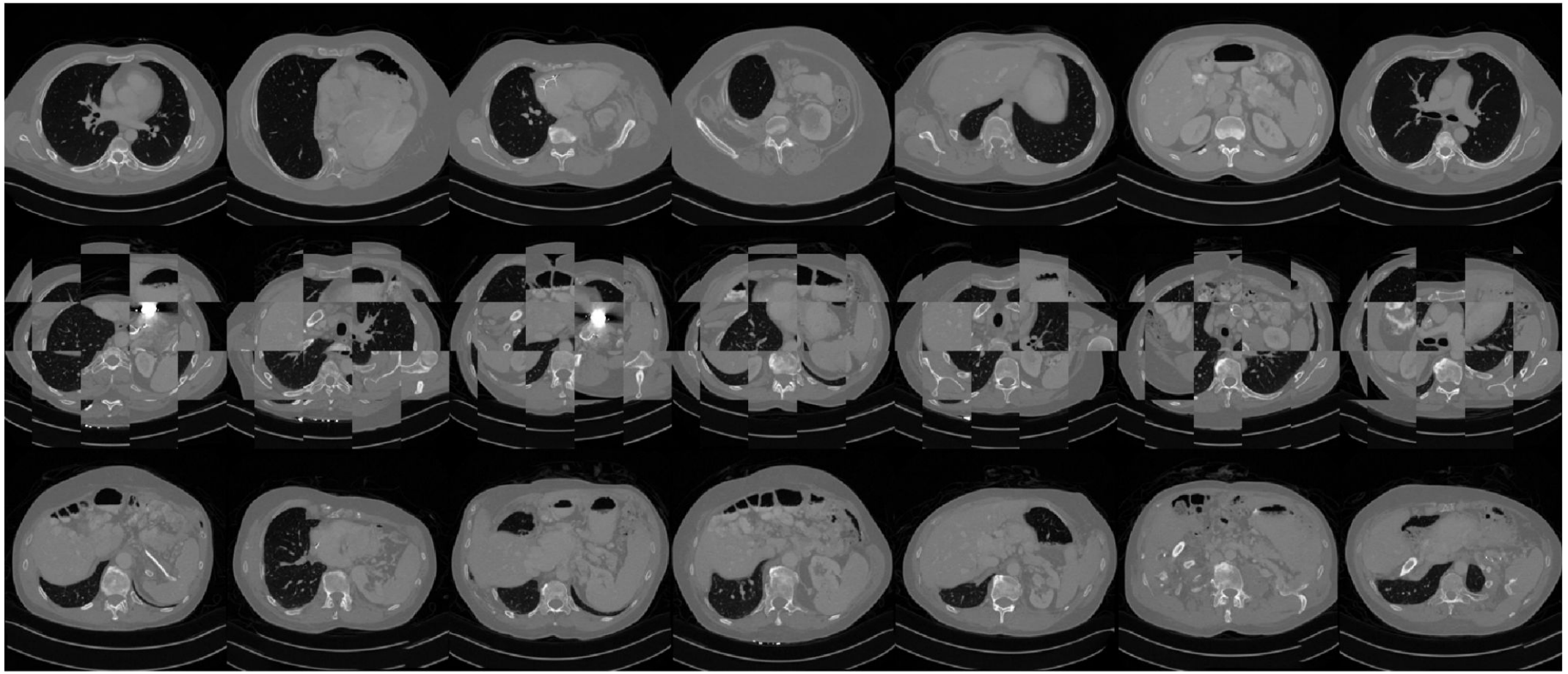


Patient-specific k-space sampling

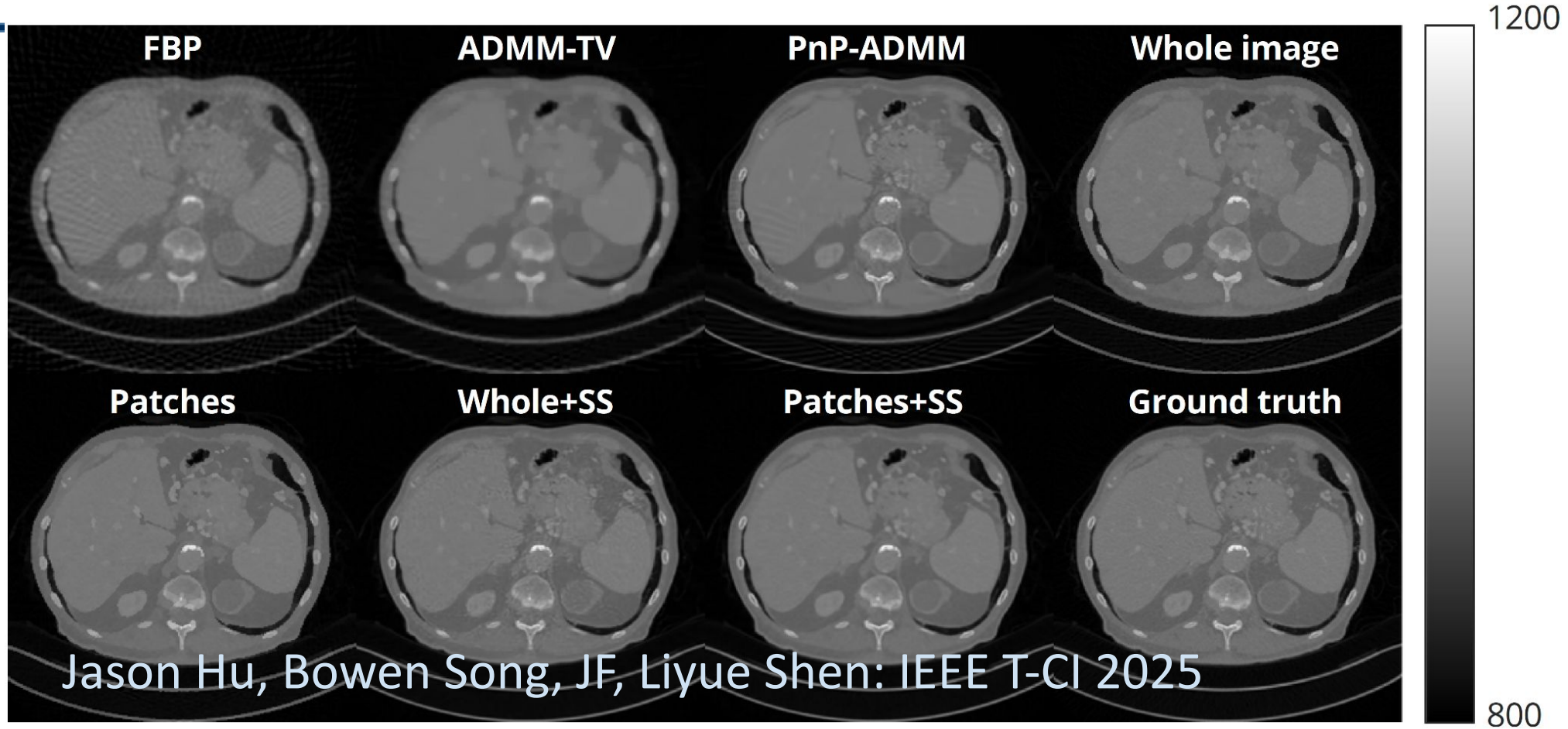
Wang, Noll, JF: arXiv 2302.13468



Generative AI for medical images (NeurIPS 2024)



Low-Dose (Sparse-View) CT Recon with GenAI



(Oct. 28 Stat Sem.)

AI Caveats

- Data requirements
- Privacy
- C02 footprint
- Interpretability
- Distribution shifts
- …

But AI is already in hospitals

- 10 vs 25

THE KING AND I
"Getting To Know You"
Rodgers & Hammerstein, 1951

It's a very ancient saying,
But a true and honest thought,
That if you become a teacher
By your pupils you'll be taught.